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CONCURRENT-SCHEDULE PERFORMANCE IN TRANSITION: CHANGEOVER DELAYS AND SIGNALED REINFORCER RATIOS

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Six pigeons were trained in experimental sessions that arranged six or seven components with various concurrent-schedule reinforcer ratios associated with each. The order of the components was determined randomly without replacement. Components lasted until the pigeons had received 10 reinforcers, and were separated by 10-s blackout periods. The component reinforcer ratios arranged in most conditions were 27:1, 9:1, 3:1, 1:1, 1:3, 1:9 and 1:27; in others, there were only six components, three of 27:1 and three of 1:27. In some conditions, each reinforcement ratio was signaled by a different red–yellow flash frequency, with the frequency perfectly correlated with the reinforcer ratio. Additionally, a changeover delay was arranged in some conditions, and no changeover delay in others. When component reinforcer ratios were signaled, sensitivity to reinforcement values increased from around 0.40 before the first reinforcer in a component to around 0.80 before the 10th reinforcer. When reinforcer ratios were not signaled, sensitivities typically increased from zero to around 0.40. Sensitivity to reinforcement was around 0.20 lower in no-changeover-delay conditions than in changeover-delay conditions, but increased in the former after exposure to changeover delays. Local analyses showed that preference was extreme towards the reinforced alternative for the first 25 s after reinforcement in changeover-delay conditions regardless of whether components were signaled or not. In no-changeover-delay conditions, preference following reinforcers was either absent, or, following exposure to changeover delays, small. Reinforcers have both local and long-term effects on preference. The former, but not the latter, is strongly affected by the presence of a changeover delay. Stimulus control may be more closely associated with longer-term, more molar, reinforcer effects.

Key words: concurrent schedules, choice, transition, generalized matching, stimulus control, key peck, pigeons

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A considerable amount of research in the experimental analysis of behavior has been concerned with choice behavior. Herrnstein (1961) reported that the proportion of responses emitted to each alternative equaled or matched the proportion of obtained reinforcers for each alternative, but subsequent research generally found that response ratios on concurrent schedules were usually less extreme than the ratios of the obtained reinforcers. This undermatching can be accommodated by the generalized matching law (Baum, 1974), that postulates a linear relationship between the logarithm of the response ratio and the logarithm of the ratio of the obtained reinforcers,

$$\log\frac{B_1}{B_2} = a\log\frac{R_1}{R_2} + \log c \qquad (1)$$

where a refers to the sensitivity to reinforcement (Lobb & Davison, 1975) and log c to the inherent bias or constant preference for one alternative. Sensitivity (a) values for concurrent variable-interval (VI) schedules are typically reported within the range of 0.60 to 0.90, with the most the most common value being around 0.80 (Taylor & Davison, 1983; Wearden & Burgess, 1982).

Studies investigating choice have focused almost exclusively on steady-state behavior (see Davison & McCarthy, 1988 for a review). In this type of research, animals are exposed to reinforcement contingencies for a sufficiently long time for preference to stabilize. The data that are included in matching analyses are those that do not indicate any systematic changes or remaining trends in behavior. Stability typically occurs after 10 to 15 sessions, although Shull and Pliskoff (1967) claimed that just 7 sessions can be sufficient.

Studies investigating choice in transition have been less numerous. Davison and Hunt-

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er (1979) arranged various dependent concurrent VI VI schedules across conditions that remained in effect for six consecutive sessions. Using multiple linear regression, sensitivity to reinforcement for the present and for the previous sessions could be quantified separately. On average, the sensitivity was 0.48 to the present session's reinforcer ratio and 0.28 for the previous session. Carryover effects were still detectable three sessions after condition changes, but had disappeared by the sixth session. Similar results were obtained by Hunter and Davison (1985) using a procedure that arranged experimental sessions with different reinforcer ratios according to a pseudorandom binary sequence (PRBS). The fact that behavior can stabilize much faster than initially assumed was further demonstrated by Schofield and Davison (1997). After subjects had been exposed to extended periods of training on a PRBS procedure, performance stabilized within a single session with no carryover from the previous sessions detectable.

It appears, therefore, that under circumstances of frequent environmental change, behavior adapts rapidly to changes in reinforcer ratios. Indeed, Mazur (1997) reported more rapid acquisition rates during conditions in which contingencies change more frequently. Acquisition rates were higher in conditions in which ratios changed every one or two sessions compared to those in which the reinforcer ratios were changed every seven to nine sessions. This speed of learning, however, declined only slightly in consecutive conditions in which the reinforcer ratios again changed every seven to nine sessions.

Davison and Baum (2000) further investigated whether the frequency of changes in the reinforcer ratios affects the speed of learning. Using a procedure introduced by Belke and Heyman (1994), they arranged seven components per session with different reinforcer ratios (27:1, 9:1, 3:1, 1:1, 1:3, 1:9 or 1:27) associated with each. The sequence of components that was arranged for each session was determined randomly without replacement. Each component was nondifferentially signaled and was followed by a 10-s blackout. In Part 1 of their experiment, components terminated after the subjects had obtained 4, 6, 8, 10 or 12 reinforcers, depending on the experimental condition. In all these conditions, sensitivity to reinforcement increased rapidly and reached a level of around 0.60 after 6 to 8 reinforcer deliveries. Their results showed that varying the frequency of reinforcer-ratio change by varying the length of the components did not have any systematic effect on the level and the rate of increase of the sensitivity values. A multiple linear-regression analysis of the data of Davison and Baum's experiment showed that the sensitivity to the previous component reinforcer ratio was around 0.20 at the beginning of a component and had almost disappeared after about six reinforcers in a component.

Although the study by Davison and Baum (2000) showed that learning can occur much faster than in regular steady-state research under certain environmental circumstances, the particular aspect of environmental variability that is responsible for this change could not be identified. Using the same procedure, Landon and Davison (2001) varied the extent, rather than the frequency, of environmental variability. In their Experiment 1, the ranges of the reinforcer ratios were varied, so that at one extreme, reinforcer ratios varied from concurrent VI 27 s Extinction (EXT) to concurrent EXT VI 27 s, and at the other extreme, the ratios did not vary, but provided equal reinforcement rates on each alternative in each component. Other intermediate reinforcer ratio ranges were 1.5:1 to 1:1.5, 3.38:1 to 1:3.38, 8:1 to 1:8, and 15.63:1 to 1:15.63. The results replicated Davison and Baum's findings of rapid increases and high levels of sensitivity to reinforcement. With larger variations in reinforcer ratios, however, sensitivities to reinforcement increased faster and reached higher levels. In Landon and Davison's Experiment 2, the range of reinforcer ratios remained constant at 27:1 to 1:27, while the presence of intermediate reinforcer ratios (9:1, 3:1, 1:1, 1:3, 1:9) was varied. This, however, did not have any systematic effect on sensitivity values. In summary, varying the range of the environmental change (Experiment 1) increased sensitivities to reinforcement, while varying the diversity (Experiment 2) and the frequency of environmental change (Davison & Baum) did not have any systematic effect.

Davison and Baum (2000) proposed a quantitative model according to which reinforcers are allocated separately to different response alternatives. Over periods of nonreinforcement, the effects of these accumulated reinforcers are gradually lost. In addition, reinforcer deliveries will be confused between the alternatives, and preference will become increasingly more indifferent over time since reinforcement. To show this effect, Davison and Baum (2002) varied the lengths of intercomponent blackout periods from 1 s to 120 s and found that carryover preference was less extreme immediately following a longer blackout. Their Experiment 2 demonstrated that this decrease in preference also occurred between reinforcer deliveries and during unsignaled 60-s extinction periods between components. Immediately after the delivery of a reinforcer, Davison and Baum observed extreme preference of up to 100:1 for the reinforced alternative. Depending on the experimental condition, this *preference pulse* subsided considerably within 10 to 20 s.

Nevertheless, Davison and Baum's (2002) results were partly inconsistent with the accumulator model. After sequences of reinforcers on the same alternative, some residual preference could still be detected even after 60-s extinction periods. Davison and Baum concluded that this could indicate the presence of a more long-term accumulator in addition to a more short-term one. Further evidence comes from a study by Landon, Davison, and Elliffe (2002) on steady-state concurrent-schedule performance. In their analyses, regressions were used to show the contribution to current preference of the locations of the previous eight reinforcers. More recent reinforcers had more effect than did more distant reinforcers. However, the intercepts to these regressions, that represent control by reinforcers more than eight back, were highly correlated with overall reinforcer ratios. Thus, preference was affected by both recent and temporally-distant reinforcer deliveries. They also found that control by recent reinforcers was more pronounced when the reinforcer ratios were more extreme.

How might the provision of discriminative stimuli that signaled different reinforcer ratios affect control by recent versus temporally-distant reinforcers? Dinsmoor (1995), for instance, conceptualized stimulus control as some kind of "transmission device" (p. 52) that reinstates the animal's past reinforcement history. From this perspective, we might expect that discriminative stimuli might signal longer-term, more molar, contingencies of reinforcement, perhaps at the expense of more local reinforcer control.

Little research has been conducted that relates behavioral transition to stimulus control. In steady-state research, the vast majority of studies of stimulus control have expressed performance in terms of response rates or number of responses emitted on each alternative. Only a few studies have investigated the effects of stimulus conditions on molar measures of preference. Hanna, Blackman, and Todorov (1992) exposed pigeons to a concurrent VI VI schedule in a procedure that compared performance in a single 5-hr session with performance in 1-hr sessions per condition. Out of a set of five different individual VI schedules, each condition arranged a different combination of individual schedules compared to the immediately preceding one. One group of subjects was first exposed to a series of conditions in which schedules were signaled by key-color stimuli followed by a series of conditions in which they were unsignaled, and vice versa for the other group. Hanna et al. found that signaling schedules of reinforcement increased the speed at which performance stabilized. With increasing time, however, relative response rates reached similar levels when schedules were not signaled. Hanna et al. concluded that the presence of discriminative stimuli decreased to time for preference to stabilize.

Miller, Saunders, and Bourland (1980) reported that sensitivities to reinforcement were lower when the two stimuli that were associated with each concurrent schedule were made less discrepant. This shows that any model of choice behavior is incomplete until it includes all three parts of the three-term-contingency (Skinner, 1974): stimulus, behavior, and reinforcement. Although such models have been offered at a molar level (e.g., Davison & Nevin, 1999), the stimulus-control aspect remains excluded from more local theories.

One purpose of the present study was to investigate how stimulus control affects choice in a highly variable environment. To what extent is preference differentially determined by more long-term versus more short-term processes when the conditions of reinforcement are signaled by discriminative stimuli compared to when they are unsignaled?

A second aim was to investigate the effect of a changeover delay (COD; Herrnstein, 1961) on preference change within components in the Belke and Heyman (1994) and Davison and Baum (2000) procedure, and in particular in terms of its effects on differential control by short- versus long-term processes. Given that the majority of concurrent-schedule reinforcers are obtained immediately following changeovers to another alternative (Dreyfus, Dorman, Fetterman, & Stubbs, 1982), preference pulses, or brief periods of extreme postreinforcement preference, will occur proportionally more often immediately following a COD and subsequent reinforcer than in any other part of the session. By arranging conditions with and without a COD, the contribution of the COD to the size and extent of preference pulses can be investigated.

The Davison and Baum (2000) procedure was used, as it has the advantage that local effects of reinforcers can be detected and the results can be directly compared with the other experiments arranging a similar procedure. Depending on the experimental condition, each session consisted of six or seven components with a particular reinforcer ratio associated with each. Each component terminated in a 10-s blackout period after 10 reinforcers had been delivered. In stimulus-control conditions, components were differentially signaled by key-flash frequencies. In the no-stimulus-control conditions, where components were not differentially signaled, we expected to replicate the results of Davison and Baum and Landon and Davison (2001), with sensitivities to reinforcement increasingly rapidly to a level of 0.60 and carryover effects disappearing after about six successive reinforcers. In the stimulus-control conditions, we expected to obtain relatively high sensitivity values at the beginning of a component (prior to any reinforcer delivery) and less pronounced carryover from the previous component. In conditions that did not arrange a COD, we expected less extreme preference with both signaled and unsignaled components compared to conditions that did arrange a COD.

Method

Subjects

Six homing pigeons, numbered 111 to 116, were housed individually and were exposed to a 16:8 hr light/dark cycle. They had prior experience working on concurrent schedules without a COD. After the daily sessions, mixed grain was provided to maintain the subjects at 85% ± 15 g of their free-feeding body weights. Water and grit were freely available at all times.

Apparatus

The subjects were housed in cages (375 mm high by 380 mm deep by 375 mm wide) that also served as the experimental chambers. The top, floor, and front wall of each cage consisted of metal grid; the back, left, and right walls were constructed of sheet metal. Each cage contained two wooden perches arranged at 90° and 75 mm above the grid floor. One perch was located 80 mm from the front wall where water and grit were located, and the second perch was located 100 mm from the right wall. Three plastic response keys (20 mm in diameter) set 114 mm apart from center to center were located on the right wall 223 mm above the second perch. Each key could be transilluminated by yellow, red, or green light-emitting diodes. Only the two side keys were used in the present experiment, and responses to illuminated keys exceeding 0.1 N were recorded as effective responses. Situated on the right wall and centered 60 mm above the perch was a 40 × 40 mm magazine aperture. During reinforcement, the key lights were extinguished, the magazine illuminated, and the hopper, containing wheat, was raised for 2.5 s. The subjects could see pigeons in other experiments, but no personnel entered the room during experimental sessions. The room lights were illuminated at 12:00 a.m. and were extinguished at 4:00 p.m. Experiments started daily at 1:00 a.m. and were conducted in succession according to the pigeon number. All experimental events were controlled by MED-PC software run on an IBM compatible PC that was located in a separate room.

Procedure

The subjects required no shaping or magazine training. Each session consisted of six

Table 1

The sequence of experimental conditions, changeover delay (COD), reinforcer ratio (L : R) for each component, and key light colors and durations (in s) arranged for each component. The overall probability of reinforcement was .037 per second throughout.

Condition	COD	Component	Reinforcer ratio	Key Lights (Red–Yellow s)
1	No	1	27:1	red–yellow 0.15–1.19
		2	9:1	red–yellow 0.50–0.84
		3	3:1	red–yellow 0.74–0.60
		4	1:1	red–yellow 0.92–0.42
		5	1:3	red–yellow 1.04–0.30
		6	1:9	red–yellow 1.13–0.21
		7	1:27	red–yellow 1.19–0.15
2, 3, 4	No	1	27:1	red–yellow 0.67–0.67
		2	9:1	red–yellow 0.67–0.67
		3	3:1	red–yellow 0.67–0.67
		4	1:1	red–yellow 0.67–0.67
		5	1:3	red–yellow 0.67–0.67
		6	1:9	red–yellow 0.67–0.67
		7	1:27	red–yellow 0.67–0.67
5	No	1	27:1	red–yellow 0.67–0.67
		2	27:1	red–yellow 0.67–0.67
		3	27:1	red–yellow 0.67–0.67
		4	1:27	red–yellow 0.67–0.67
		5	1:27	red–yellow 0.67–0.67
		6	1:27	red–yellow 0.67–0.67
6	No	1	27:1	green only
		2	27:1	green only
		3	27:1	green only
		4	1:27	green only
		5	1:27	green only
		6	1:27	green only
7	2 s	1	27:1	green only
		2	27:1	green only
		3	27:1	green only
		4	1:27	green only
		5	1:27	green only
		6	1:27	green only
7b	2 s	1	27:1	green only
		2	9:1	green only
		3	3:1	green only
		4	1:1	green only
		5	1:3	green only
		6	1:9	green only
		7	1:27	green only
8	2 s	1	27:1	red–yellow 0.67–0.67
		2	9:1	red–yellow 0.67–0.67
		3	3:1	red–yellow 0.67–0.67
		4	1:1	red–yellow 0.67–0.67
		5	1:3	red–yellow 0.67–0.67
		6	1:9	red–yellow 0.67–0.67
		7	1:27	red–yellow 0.67–0.67
9, 10	2 s	1	27:1	red–yellow 0.15–1.19
		2	9:1	red–yellow 0.50–0.84
		3	3:1	red–yellow 0.74–0.60
		4	1:1	red–yellow 0.92–0.42
		5	1:3	red–yellow 1.04–0.30
		6	1:9	red–yellow 1.13–0.21
		7	1:27	red–yellow 1.19–0.15
11	2 s	1	27:1	red–yellow 0.67–0.67
		2	9:1	red–yellow 0.67–0.67
		3	3:1	red–yellow 0.67–0.67
		4	1:1	red–yellow 0.67–0.67
		5	1:3	red–yellow 0.67–0.67
		6	1:9	red–yellow 0.67–0.67
		7	1:27	red–yellow 0.67–0.67
12	No	1	27:1	red–yellow 0.15–1.19
		2	9:1	red–yellow 0.50–0.84
		3	3:1	red–yellow 0.74–0.60
		4	1:1	red–yellow 0.92–0.42
		5	1:3	red–yellow 1.04–0.30
		6	1:9	red–yellow 1.13–0.21
		7	1:27	red–yellow 1.19–0.15
13	No	1	27:1	red–yellow 0.67–0.67
		2	9:1	red–yellow 0.67–0.67
		3	3:1	red–yellow 0.67–0.67
		4	1:1	red–yellow 0.67–0.67
		5	1:3	red–yellow 0.67–0.67
		6	1:9	red–yellow 0.67–0.67
		7	1:27	red–yellow 0.67–0.67

or seven components, depending on the experimental condition. The MED-PC program determined randomly which component was in effect at the beginning of a session. Both side keys were lit and were extinguished during reinforcement or at the termination of a component. The components determined which concurrent exponential VI schedules were in effect.

Conditions 1 to 4 and 7b to 13 comprised seven components that arranged reinforcer ratios of 27:1, 9:1, 3:1, 1:1, 1:3, 1:9 and 1:27, and Conditions 5 to 7 arranged six components with three 27:1 reinforcer ratios and three 1:27 reinforcer ratios (Table 1). Each component terminated when the subject had obtained ten reinforcers on either key, after which the key lights extinguished and a 10-s blackout-interval commenced. The component that followed was determined randomly without replacement by the MED-PC program. The overall reinforcer rate remained constant at one reinforcer per 27 s across components and conditions. This was done by interrogating a probability gate set at .037 every second.

Depending on the experimental condition, components were either signaled or unsignaled. In Conditions 1, 9, 10, and 12, both side keys were simultaneously illuminated by

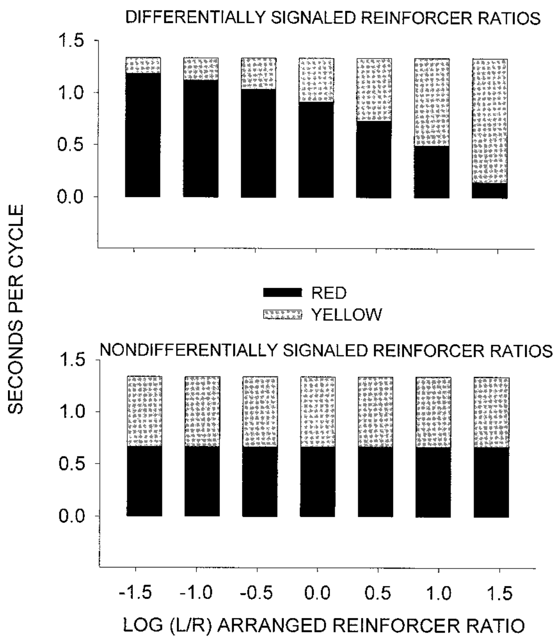

Fig. 1. Seconds per cycle of red and yellow key lights for conditions in which components were differentially signaled (Conditions 1, 9, 10, & 12) and in which they were nondifferentially signaled (Conditions 2, 3, 4, 5, 8, 11, & 13). In Conditions 6, 7 and 7b, the response keys were lit green.

red–yellow-light alternations of a cycle length of 1.34 s. For the components arranging 27:1, 9:1, 3:1, 1:1, 1:3, 1:9, and 1:27 reinforcer ratios, the red light came on for 1.19 s, 1.13 s, 1.04 s, 0.92 s, 0.74 s, 0.50 s, and 0.15 s, respectively (Table 1). In Conditions 2, 3, 4, 5, 7b, 8, 11, and 13, all components were nondifferentially signaled by red and green flashes of 0.67 s each within the 1.34 s cycle, and in Conditions 6 and 7, both response keys were continuously lit green. These procedures are diagrammed in Figure 1. Conditions 3 and 4 were continuations of Condition 2, and Condition 10 was a continuation of Condition 9. Condition 11 was a replication of Condition 8, Condition 12 a replication of Condition 1, and Condition 13 was a replication of Conditions 2, 3, and 4.

Two concurrent VI schedules were arranged dependently (Stubbs & Pliskoff, 1969) on the left and the right response keys. Whenever a reinforcer was arranged on one alternative, timing for both alternatives stopped until this reinforcer had been obtained. From Condition 7 onwards, a 2-s COD (Herrnstein, 1961) was implemented. This had the effect that a reinforcer on an alternative could not be obtained within a period of 2 s following the first response to that alternative after responding to the other alternative.

Sessions ended in blackout either after all components had been completed or after 45 min had elapsed. Conditions were in effect for 50 sessions, and the data from the last 35 sessions were used for the analyses. Condition 7b was conducted as a brief transition from Condition 7 to Condition 8, and lasted only 20 sessions.

RESULTS

The data recorded were the times at which each experimental event occurred over the last 35 sessions of each condition.

The first set of analyses determined whether data averaged across individual subjects were representative of individual performance. Figure 2 shows the logarithms (base 10) of the ratios of left- to right-key responses before each successive reinforcer in Condition 1 for all individual pigeons and their pooled data (number of responses and reinforcers). In this condition, components were differentially signaled by red–yellow flashes, and no COD was arranged. Response ratios appeared to have stabilized after the second or third reinforcer in a component. From this point on, log response ratios remained relatively constant and were separated from each other in an order that reflected the arranged reinforcer ratios. Across individuals, this pattern was consistent, and only the extent to which the response ratios were separated from each other differed. The similarity across individuals allows the assumption that the group data provide a reasonable representation of the individual results.

To confirm this conclusion, a similar analysis was carried out on Condition 11 (Figure 3) that arranged a 2-s COD and no differential signaling of components. The group data demonstrated a consistent pattern that also was evident in the response ratios for all individual pigeons. Before the first reinforcer, log response ratios for all components were generally close to zero, but, with increasing numbers of successive reinforcers, they moved apart according to the component re-

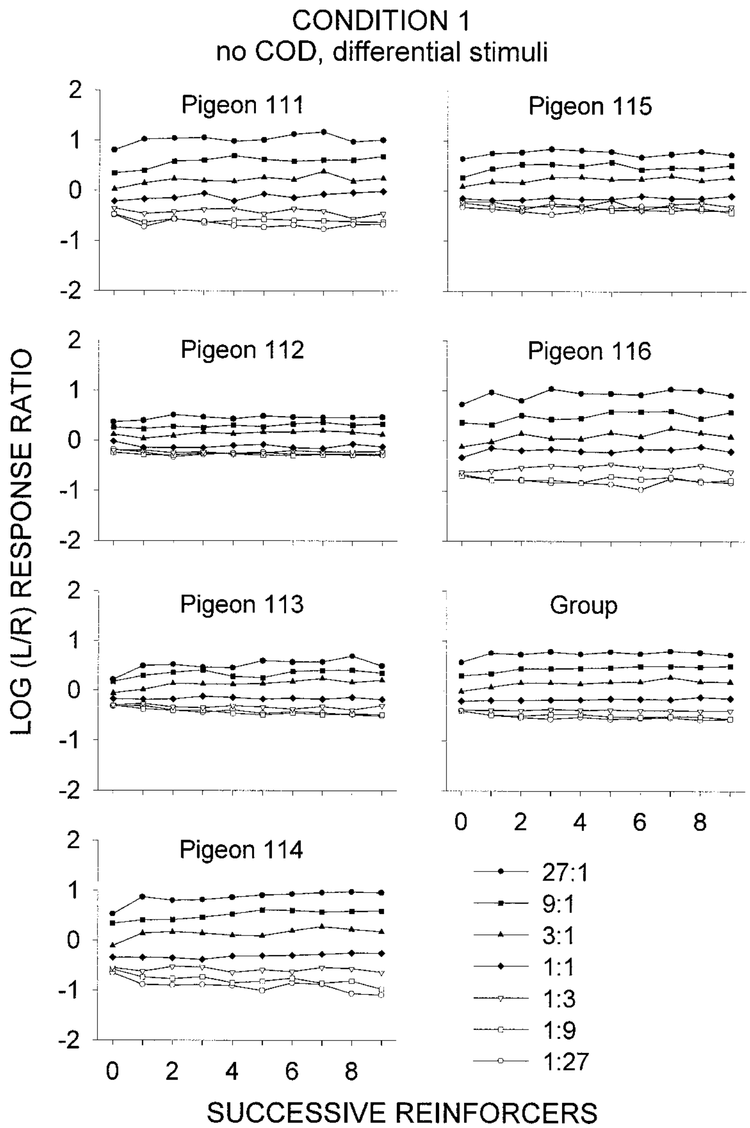

Fig. 2. Log left-/right-key response ratios prior to each successive component reinforcer in each of the seven components for each pigeon. Components were differentially signaled and no COD was arranged.

inforcer ratios. For Pigeons 111, 112 and 114, log response ratios before the first reinforcer were negative for all components, indicating a bias towards the right response key. For all pigeons, initial log response ratios did not reflect the arranged reinforcer ratios in the current component—in components arranging more reinforcers for the left alternative, preference prior to the first reinforcer tended to be more biased towards the right alternative, whereas the opposite was the case for the components with higher reinforcer rates for the right alternative. This effect was reported by Davison and Baum (2000), who suggested this resulted from carryover from the prior component.

Having shown that group data were representative of individuals, the remaining analyses will use only group data. Figures 4 and 5 show the log response ratios as a function of successive component reinforcers for Conditions 1 through 13. A similar pattern was present in all conditions in which individual components were signaled (Conditions 1, 9,

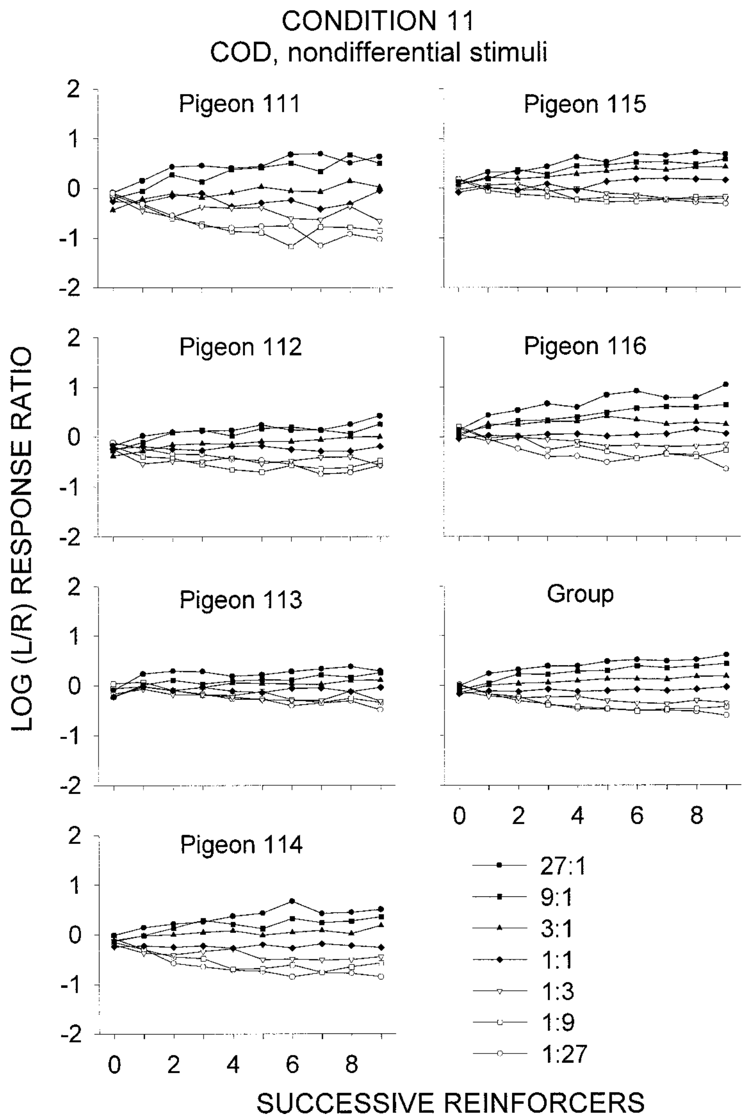

Fig. 3. Log left-/right-key response ratios prior to each successive component reinforcer in each of the seven components for each pigeon. Components were nondifferentially signaled and 2-s COD was arranged.

10, and 12). As noted above in relation to Condition 1 (Figure 2), log response ratios were in the direction of the arranged component reinforcer ratios before the first reinforcer was obtained. Log response ratios increased slightly over the first two to three component reinforcers and thereafter remained relatively constant. In all conditions in which components were unsignaled, log response ratios gradually shifted away from approximate indifference prior to the first reinforcer towards the direction of the arranged component reinforcer ratio. Preference typically was more extreme with more extreme reinforcer ratios. Log response ratios before the first reinforcer were often inversely related to the reinforcer ratios. The fact that this effect was particularly pronounced in Condition 7 (1:27 and 27:1 components only) favors the explanation that it results from carryover from a previous component (Figure 4). Carryover between components would be expected to be stronger in this condition than in conditions that included inter-

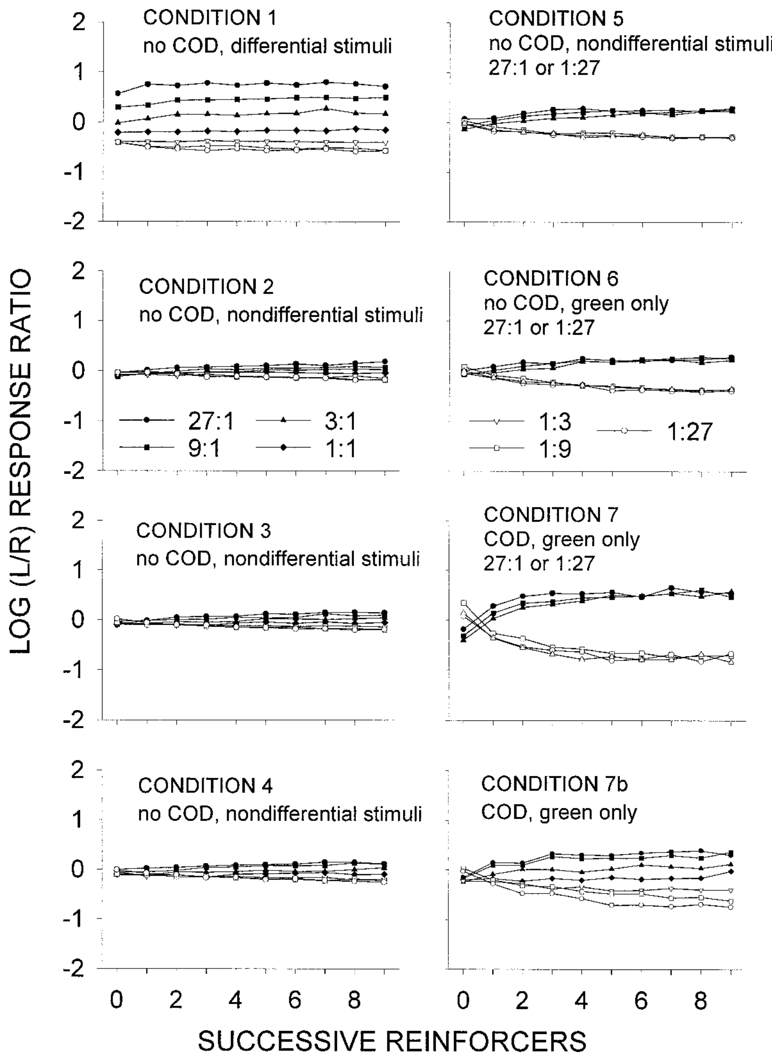

Fig. 4. Log left-/right-key response ratios prior to each successive component reinforcer for Conditions 1 through 7b. The data are sums across the six pigeons. In conditions in which reinforcer ratios are unspecified, they ranged from 1:27 to 27:1 over 7 levels. In Conditions 5, 6 and 7, three components arranged a 1:27 reinforcer ratio, and three components arranged a 27:1 reinforcer ratio.

mediate reinforcer ratios. Davison and Baum (2000) found that response ratios before the first few reinforcers in components were affected by the reinforcer ratio in previous components. Although log response ratios before the first component reinforcers in Conditions 1, 9, 10, and 12 (differentially-signaled components) were not reversed, initial preference at this point was less extreme, which could reflect a small amount of carryover from the previous component.

Preference was generally more extreme in conditions that arranged a COD than in those that did not. Conditions 9 and 10 using signaled reinforcer ratios were replications of Condition 1, but with a COD. Log response ratios for the most extreme reinforcer-ratio components in Conditions 9 and 10 ranged from −1.12 to 1.09 and −1.22 to 1.16, respectively, compared to −0.59 to 0.79 in Condition 1. Similar differences can be observed in conditions that did not signal component reinforcer ratios. For example, compare Conditions 2, 3, and 4 (no COD, Figure 4) with Conditions 8 and 11 (COD, Figure 5).

The results shown in Figures 4 and 5 also

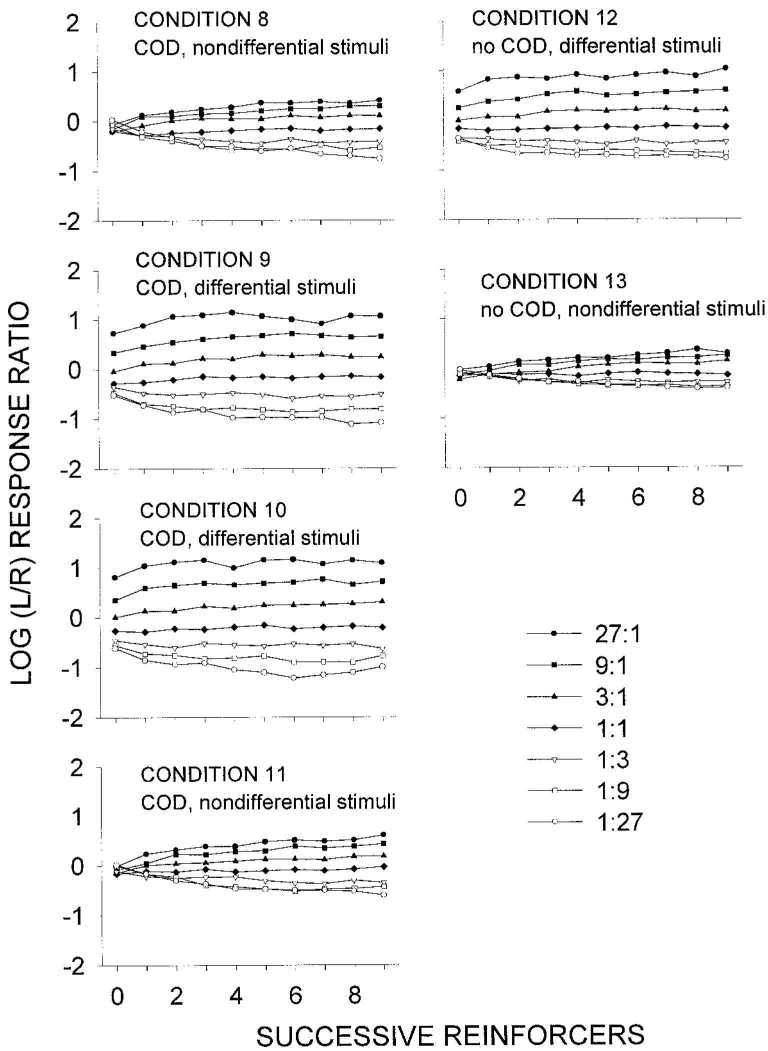

Fig. 5. Log left-/right-key response ratios prior to each successive component reinforcer for Conditions 8 through 13. The data are sums across the six pigeons. In conditions in which reinforcer ratios are unspecified, they ranged from 1:27 to 27:1 over 7 levels.

document changes in performance produced by the sequence of conditions arranged. Compared to Condition 1 where components were signaled, preference in Condition 2 where components were not signaled was relatively unchanged by successive reinforcers (Figure 4), producing log response ratios at the end of components ranging from −0.19 to 0.19. In Conditions 3 and 4, which were direct continuations of Condition 2, end-of-component log response ratios were similar, with ranges from −0.20 to 0.15 and −0.25 to 0.15, respectively. Condition 13 was a direct replication of Conditions 2, 3, and 4, and components ended with log response ratios ranging from −0.42 to 0.37 (Figure 5). Similar effects of exposure to a COD are also seen in Condition 12, which was a direct replication of Condition 1. End-of-component preference in Condition 12 ranged from −0.78 to 0.96 as compared to −0.59 to 0.79 in Condition 1.

Log response ratios did not appear to change when components were signaled nondifferentially by green light instead of red–yellow flashes. In conditions in which components were differentially signaled, log response ratios in components arranging a

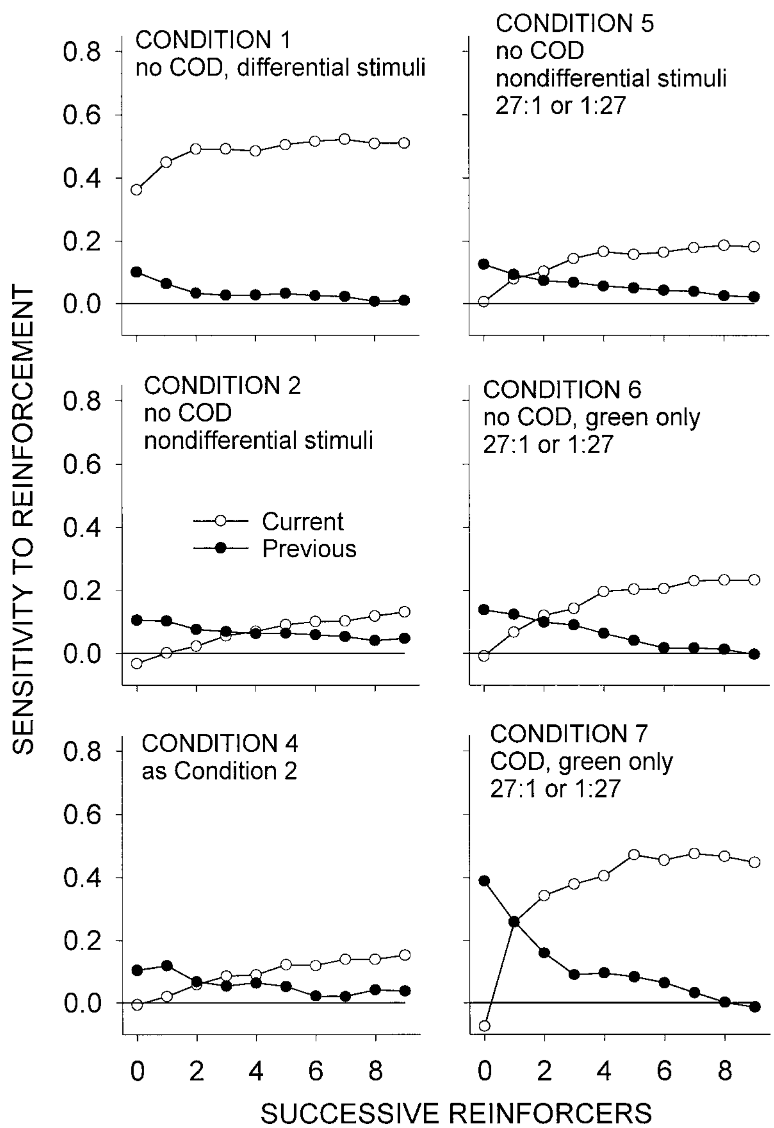

Fig. 6. Sensitivity to reinforcement to the current and prior components as a function of successive component reinforcers in Conditions 1 and 2, and 4 through 7. The data are sums across the six pigeons. In conditions in which reinforcer ratios are unspecified, they ranged from 1:27 to 27:1 over 7 levels.

higher reinforcement rate on the right alternative (1:3, 1:9, & 1:27) were generally more similar to each other than in components where the left provided the higher reinforcement rate. The data for Condition 6, in which components were all associated with the same green key color, were similar to those for Condition 5 where nondifferential flash frequencies were used. Similarly, log response ratios did not appear to differ between Condition 8 (nondifferential stimuli) as compared to Condition 7b (green keys only).

Following the procedure used by Davison and Baum (2000), multiple linear regressions were used to estimate both sensitivities to current and previous component reinforcer ratios as a function of successive reinforcers in components. The dependent variables in this analysis were the log ratios of responses emitted between successive reinforcers in each component, and the independent variables were the log reinforcer ratios in the present and in the previous components. The results are shown in Figures 6 and 7. Carryover in

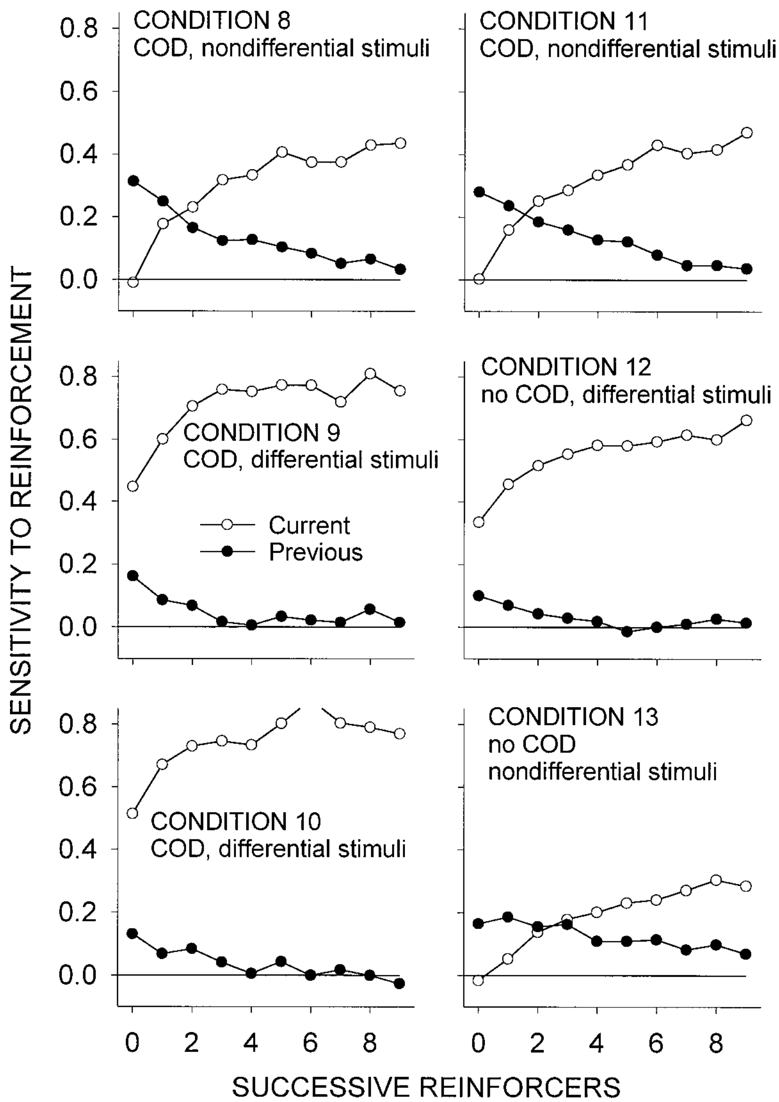

Fig. 7. Sensitivity to reinforcement to the current and prior components as a function of successive component reinforcers in Conditions 8 through 13. The data are sums across the six pigeons. In conditions in which reinforcer ratios are unspecified, they ranged from 1:27 to 27:1 over 7 levels. One data point in Condition 10 fell off the graph at 0.88.

conditions with no COD appeared to be smaller than when a COD was used. Values of carryover sensitivity to reinforcement to the previous component prior to the first component reinforcer ranged from 0.10 to 0.16 in Conditions 2, 4, and 13 (nondifferential stimuli, no COD), compared to 0.31 and 0.28 in Conditions 8 and 11 (nondifferential stimuli, COD). Similarly, although not as pronounced, carryover values at the beginning of components in Conditions 9 and 10 (COD) were higher than those in Conditions 1 and 12 (no COD).

When individual components were signaled by differential stimuli, the degree of carryover from the previous components was smaller than when they were nondifferentially signaled. In Conditions 8 and 11, sensitivity to the prior component reinforcer ratio before the first reinforcer was 0.31 and 0.28, respectively, and remained above zero throughout the component (Figure 7). In Conditions

9 and 10, however, when components were differentially signaled, sensitivity values to the prior component were 0.16 and 0.13 prior to the first reinforcer, and decreased to zero after around five successive reinforcers. This difference in carryover between signaled and unsignaled components was smaller when no COD was arranged. Carryover sensitivity values in Condition 1 were similar to those in Conditions 2 and 4, although these differences were somewhat larger in later replications of these conditions (following exposure to a COD) as can be seen by comparing Condition 12 (differential stimuli) with Condition 13 (nondifferential stimuli, Figure 7).

In conditions in which components were signaled, sensitivities to the present component were at a reasonably high level from the beginning of a component (Figure 7). In Conditions 1, 9, 10, and 12, sensitivities ranged from 0.33 to 0.51 before the occurrence of the first reinforcer. Sensitivities in conditions with nondifferentially signaled components, however, ranged from −0.03 to 0.01 (Figures 6 & 7). Consistent with the log response ratio data shown in Figure 4, sensitivity prior to the first component reinforcer in Condition 7 was strongly negative.

In all conditions, sensitivity to reinforcement in the present component increased with successive component reinforcers. Sensitivity values generally appeared to have reached reasonably stable levels within components, although in some conditions there might have been a slightly increasing trend remaining after 10 reinforcers (Figures 6 & 7).

When components were signaled, sensitivity to reinforcement reached values higher then when components were not signaled. Figure 8 shows the average current-component sensitivity to reinforcement averaged over the last three component reinforcers (Reinforcers 8, 9 and 10) for all conditions. Mean sensitivity values in Conditions 1 and 12 (differentially signaled components) were 0.51 and 0.63, respectively, as compared to Conditions 2 through 6 and Condition 13 (nondifferentially signaled components) that had sensitivities ranging from 0.12 to 0.29. Sensitivity to reinforcement was also higher in signaled than in unsignaled components when a COD was arranged. Sensitivities were 0.76 and 0.79 in Conditions 9 and 10 (differentially signaled components) and 0.46, 0.41, and 0.43 in Conditions 7, 8, and 11 (nondifferentially signaled components).

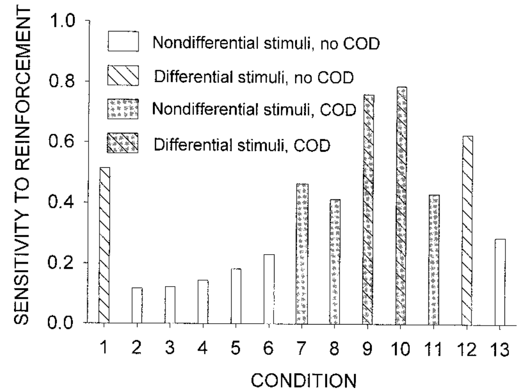

Fig. 8. Current-component sensitivity to reinforcement averaged over the last three component reinforcers for each major experimental condition. The data are sums across the six pigeons.

Sensitivity values in conditions arranging CODs were always higher than in corresponding conditions without COD (Figure 8). This is shown by comparing Conditions 9 and 10 with Conditions 1 and 12, and by comparing Conditions 8 and 11 with Conditions 4 and 13. More obviously, introducing a COD in Condition 7 considerably increased sensitivity to reinforcement compared with Condition 6, that also arranged only 27:1 and 1:27 components with nondifferential green keys.

Sensitivity values appeared to increase with continued exposure to the same experimental conditions. Sensitivity to reinforcement at the end of a component increased from Condition 2 (0.13) through to Condition 4 (0.15). This trend, however, was significant for only 4 of the 6 subjects (Kendall trend test, two-tailed, $p < .05$). In Condition 9, sensitivity was 0.75 as compared to 0.77 in Condition 10, again significant for 4 of the 6 subjects (randomization test, $N = 9$, $p < .05$).

The effects of exposure to CODs discussed above in relation to the log response-ratio analyses were confirmed by the sensitivity to reinforcement measures. In all direct replications, final sensitivity values after prior exposure to a COD were higher than before exposure to a COD. Sensitivity values before the last component reinforcer were significantly higher for all pigeons in Condition 12 than in Condition 1 and for all pigeons in Condition 13 compared to Condition 4, but for

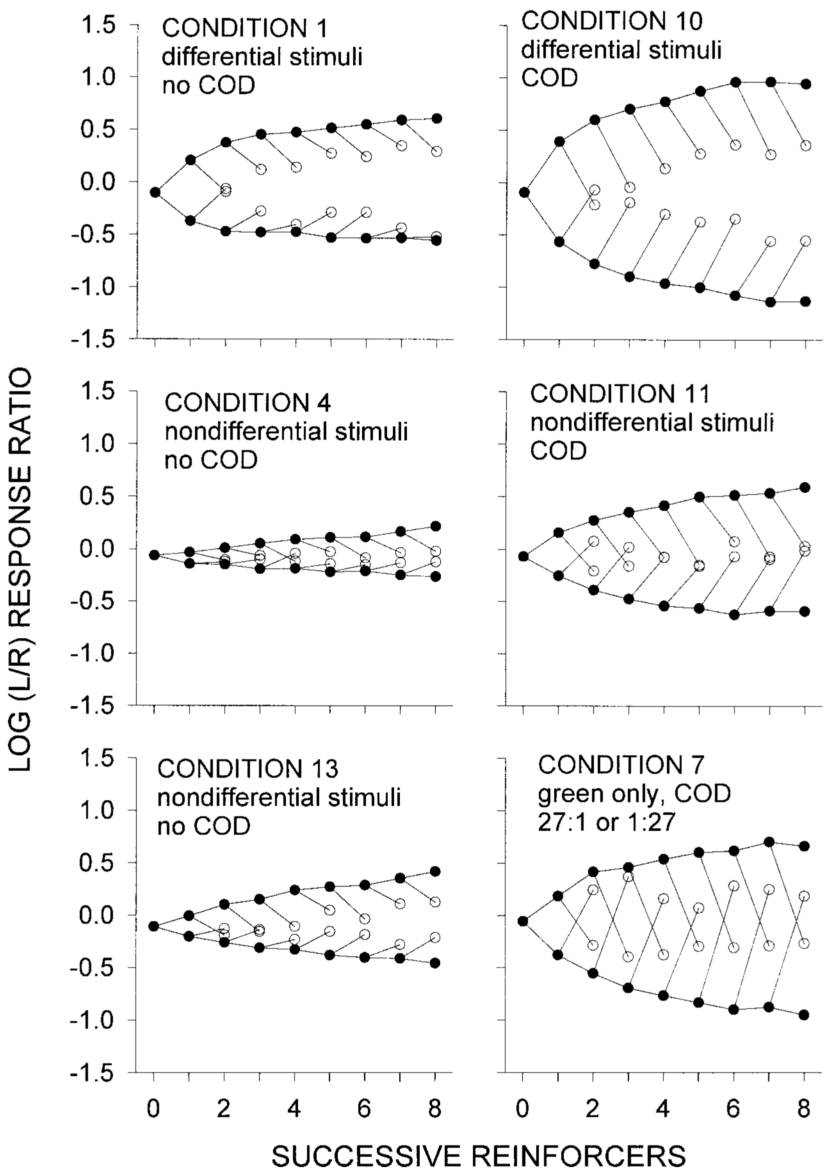

Fig. 9. Log left-/right-key response ratios prior to each successive component reinforcer for selected sequences of reinforcers in components comparing conditions that arranged (right column) and did not arrange (left column) CODs. The filled circles represent log response ratios after reinforcers sequences and the empty circles sequence discontinuations. The data are sums across the six pigeons.

only three pigeons in Condition 11 compared to Condition 8, both of which arranged a COD (randomization test, two-tailed, $N = 9$).

Figure 9 shows log response ratios for selected conditions for sequences of successive reinforcers on the same alternative and the discontinuation of these sequences. Log response ratios for sequences (filled circles) increased for left-key reinforcers, and decreased for right-key reinforcers. *Discontinuations* (empty circles) moved performance in the opposite directions from the trend of the continuations. For all conditions, the data for left- and right-key reinforcers appeared approximately symmetrical. Note that the log response ratios commenced close to zero before any reinforcers were delivered because these data are taken from all components.

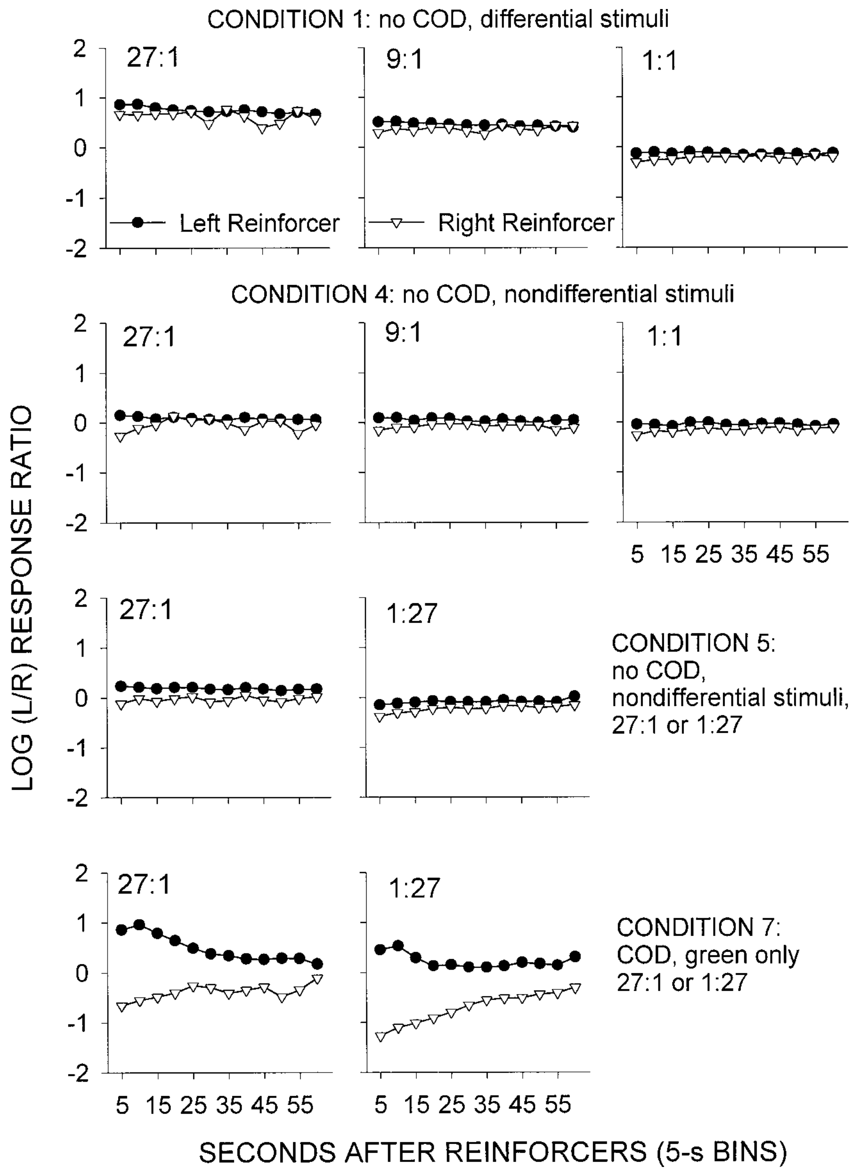

Fig. 10. Log left-/right-key response ratios in successive 5-s time bins following left- and right-key reinforcers for selected conditions and components.

With successive reinforcers, log response ratios became more extreme, and appeared to increase only slightly, if at all, towards the end of a component. In conditions in which components were signaled, log response ratios moved apart more compared to unsignaled-component conditions (Condition 1 vs. 4, and Condition 10 vs. 11). It also appeared that differential signaling, as compared to nondifferential signaling, did not affect the absolute size of the discontinuation effects. Overall, discontinuation effects were more pronounced in conditions arranging a COD.

The following analyses investigated changes in preference following all reinforcer deliveries in a component. Figures 10 and 11 show the log response ratios during the first 55 s (5-s time bins), or until a subsequent reinforcer, after reinforcers for selected conditions and components. At this level of analysis, there were no systematic differences between subjects, justifying the use of group

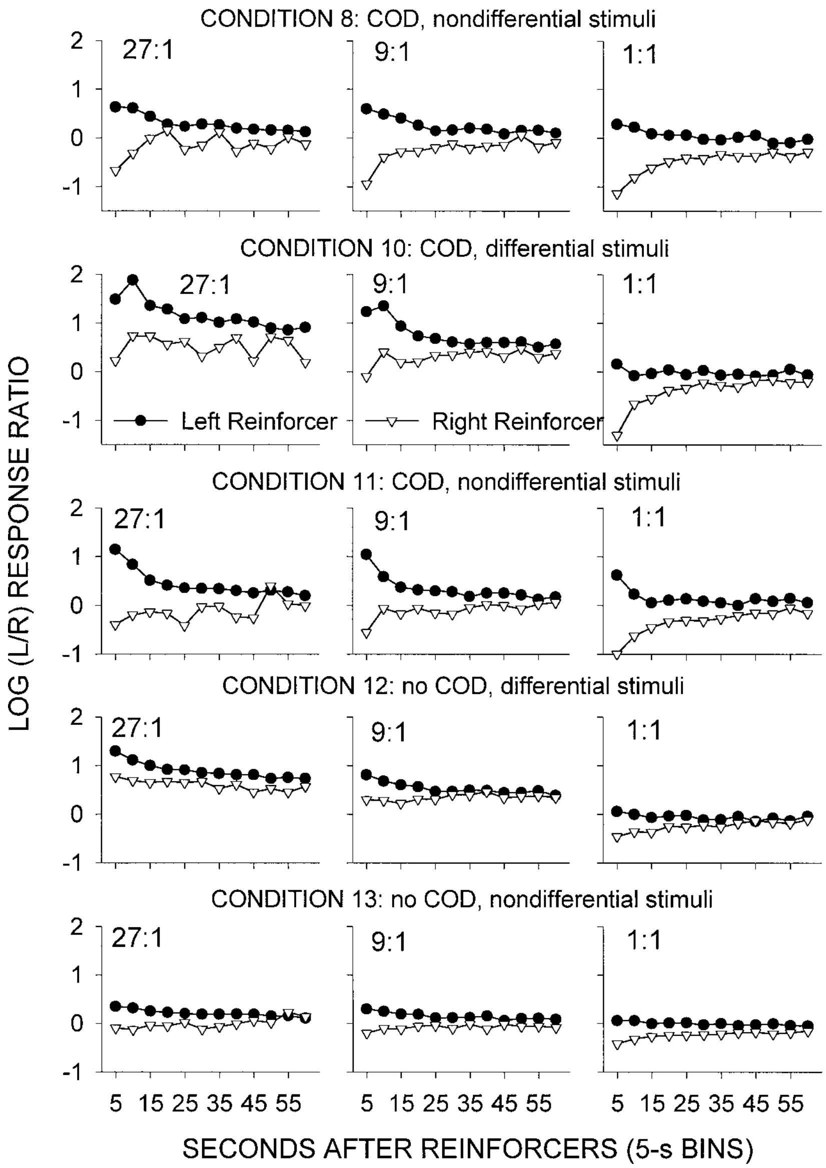

Fig. 11. Log left-/right-key response ratios in successive 5-s time bins following left- and right-key reinforcers for selected conditions and components.

data. In Conditions 5 and 7, which arranged three 27:1 and three 1:27 components, the data for each component type were summed together. In conditions arranging no COD (1, 4, 5, 12, and 13), preference remained at relatively constant levels with increasing time since a component reinforcer. By contrast, when a COD was arranged (Conditions 8, 10, and 11), log response ratios were extreme immediately after a reinforcer, and then gradually moved towards indifference. After appproximately 25 s, preference stabilized around a level that reflected the arranged reinforcer ratios in individual components. In Condition 7 (nondifferential stimuli, 27:1 or 1:27 reinforcer ratios), preference appeared to move to indifference relatively slowly (Figure 10), and log response ratios 50 s after a left and right reinforcer remained considerably different than in other experimental conditions.

In general, the size and duration of pref-

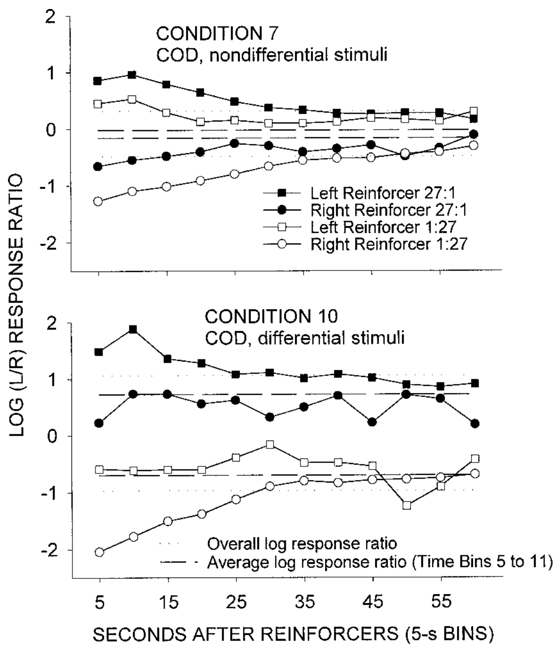

Fig. 12. Log left-/right-key response ratios in successive 5-s time bins following left- and right-key reinforcers occurring in the 27:1 and 1:27 reinforcer-ratio components in Conditions 7 and 10. Also shown are the overall log response ratios in these components, and the average log response ratio in Time Bins 5 to 11.

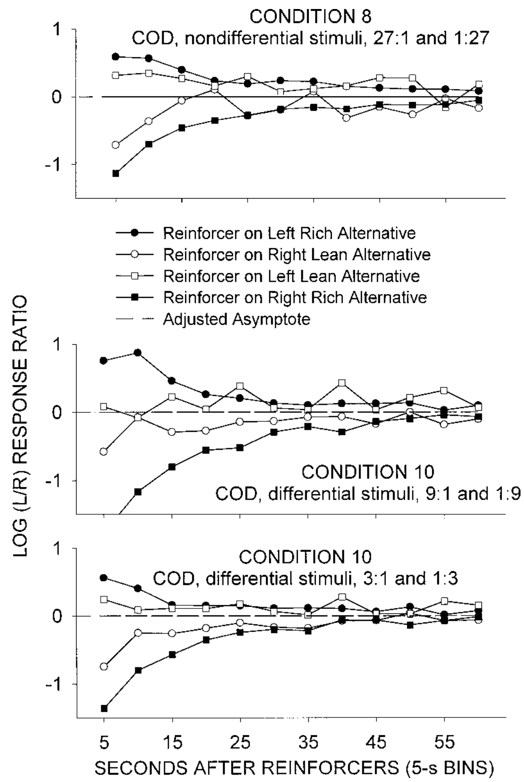

Fig. 13. Log left-/right-key response ratios in successive 5-s time bins following reinforcers in the higher and lower reinforcer rate alternatives in selected conditions and components. One data point for Condition 10, 9:1 and 1:9 reinforcer ratio, fell off the graph at −1.77.

erence pulses following reinforcers appeared similar regardless of whether components were signaled or unsignaled and regardless of whether a COD was arranged. Differences could only be observed in the levels around which preference stabilized in different components. When no differential stimuli were arranged, stable log response levels tended to be more similar between components. Compared to Condition 1 (differentially signaled components), for instance, stable log response values in Condition 4 (nondifferentially signaled components) differed to a much smaller extent (Figure 10). This effect of signaling components was more pronounced when a COD was implemented, as can be seen when comparing Condition 10 with Condition 11 (Figure 11).

Figure 12 shows preference following a left- and right-key reinforcer in the 27:1 and 1:27 components in Conditions 7 (nondifferential stimuli) and 10 (differential stimuli). For Condition 7, the data were summed across all three 27:1 and 1:27 components. The dotted lines in the graphs indicate the overall response ratios calculated using total numbers of responses in a component. Also shown are the average log response ratios in Time Bins 5 to 11 following left and right reinforcers. Figure 12 shows that the overall log response ratio in a component was more extreme than the level at which preference stabilized at the end of components. For each of the seven components, the difference was significant (randomization test, two-tailed, $N = 7$) for both Condition 7 ($p = .02$) and Condition 10 ($p = .01$). Figure 12 suggests that preference pulses on more-frequently reinforced alternatives were greater in both size and duration than those on less-frequently reinforced alternatives.

To show these effects more clearly, Figure 13 shows the deviation of preference-pulse values from apparently stable preference in Time Bins 5 to 11 for two pairs of components in Conditions 8 and 10. It is again evident in all comparisons that reinforcers that occurred on a richer alternative resulted in greater changes in preference than when they occurred on a leaner alternative. In Condition 8, for example, preference pulses following reinforcers on the left key were more pronounced in a 27:1 (filled circles) component than in a 1:27 component in which fewer reinforcers were arranged for left-key responses than for right-key responses (open squares). The same difference could be observed when comparing response pulses when the right key was the rich alternative (filled squares) or when it was the lean alternative (open circles). In addition, preference pulses following right-key reinforcers tended to be more pronounced than for left-key reinforcers. Log response ratios in Condition 10, for instance, were −1.36 and −0.75 for right-key reinforcers in a 1:3 and 3:1 component, respectively, compared to 0.24 and 0.56 following a left-key reinforcer. Thus, reinforcers that occurred on the right key resulted in more extreme and longer-lasting response-ratio changes than those occurring on the left key.

DISCUSSION

The results of the present experiment confirmed the findings of Davison and Baum (2000, 2002) and Landon and Davison (2001) that behavior can adapt quickly to rapidly changing reinforcer ratios. Log response ratios in components quickly moved apart in components following the arranged and obtained reinforcer ratios (Figures 2 to 5). Increasing numbers of successive same-alternative reinforcers had decreasing effects on changing response ratios. Typically, sensitivities to reinforcement appeared to have reached relatively high, if not stable, levels by the end of components (Figures 6 & 7). Discontinuations (termed "disconfirmations" by Davison & Baum), in which a series of same-alternative reinforcers was followed by a reinforcer on the other alternative, moved preference strongly towards or even beyond indifference. In addition to these replications of previous results, the present research has shown effects of differentially signaling components: Even before the first reinforcer had been obtained, preference in signaled components was closely related to the component reinforcer rate, and further component reinforcers did not increase preference, or sensitivity to reinforcement, appreciably. The present research also documented a unidirectional effect on choice of exposure to CODs: Preference and sensitivity to reinforcement were more extreme in no-COD conditions following exposure to a COD than before exposure.

Effects of Signaling Reinforcer Ratios

The results from conditions with a COD and nondifferential stimuli (Conditions 8 & 11) are directly comparable to Condition 3 of Davison and Baum's (2000) experiment and to Condition 12 of Landon and Davison's (2001) experiment in which the same set of seven unsignaled reinforcer ratios as used here were arranged for components ending after 10 reinforcers. All three experiments showed that preference was controlled by the component reinforcer ratios, and that sensitivity to reinforcement increased progressively within components (Figure 7). Consistent with previous reports, sensitivities to reinforcement in the present experiment reached a level of around 0.40 in Condition 8 and 0.50 in Condition 11 (Figure 7). Davison and Baum (2000) reported sensitivities to reinforcement of around 0.50 in their Condition 3, and Landon and Davison obtained a value of around 0.50 to 0.60 in their Condition 12.

When differential stimuli were arranged, log response ratios were under the control of the current-component reinforcer ratios before the delivery of the first component reinforcer, whether a COD was arranged or not (Figures 4 & 5). With increasing numbers of component reinforcers, log response ratios changed by small amounts, quickly reaching their final within-component levels, again independently of the presence or absence of the COD. When components were not differentially signaled, however, choice was close to indifference prior to the first component reinforcer (and often in a direction opposite to the current reinforcer ratio), and then changed progressively with further component reinforcers according to the component reinforcer ratio in effect.

Signaling component reinforcer ratios produced systematically different component preferences at the beginning of a component, unlike preferences in conditions without differential stimuli. In the latter, the separation of preference developed with increasing numbers of component reinforcers. In components that arranged higher reinforcer rates for the left alternative, log response ratios approximated the reinforcer ratios more closely than in components arranging higher reinforcer rates for the right alternative (Figures 4 & 5). The durations of the red flashes were logarithmically spaced, but as the total cycle length was constant, yellow flash durations were not logarithmically spaced (Table 1). The asymmetrical effects of the set of stimuli suggest that the subjects were generally discriminating on the duration of the yellow flashes, that, because of the spacing of the durations, would be more discriminable between components with higher left-key reinforcer rates than for higher right-key reinforcer rates.

Sensitivity values were generally 0.20 to 0.30 higher throughout components in conditions in which components were differentially signaled (Figure 8) than in unsignaled components. It is unclear whether signaling per se resulted in higher sensitivity values or whether this resulted from component sensitivities commencing in components at higher levels. Indeed, when components were differentially signaled, log response ratios changed less with successive reinforcers compared to when components were not signaled (Figures 4 & 5), indicating that the effect of successive reinforcers was larger in the latter conditions.

The finding that preference prior to the first reinforcer in signaled components was slightly less extreme than preference later in a component may have resulted from a carryover effect from the previous component. Because components were sampled randomly without replacement, the previous component was more likely to have arranged a reinforcer ratio favoring the other alternative. The amount of carryover from the previous component, however, was less in conditions with differential stimuli (Figures 6 & 7) than in conditions with nondifferentially signaled components.

Signaling individual components did not appear to have any effect on the presence or absence of preference pulses. Between the occurrence of successive reinforcers, log response ratios moved towards indifference regardless of whether the reinforcer ratios were signaled or not (Figures 10 & 11). Additionally, differential signaling did not affect the extent to which preference shifted following a discontinuation of same-key reinforcer sequences. Although log response ratios shifted more towards or beyond indifference when components were not differentially signaled, the size of the changes were similar (Figure 9). This demonstrates that short- and long-term control are not mutually exclusive: Signaling reinforcer ratios established control over preference by long-term reinforcer ratios without eliminating short-term control.

The largest effects were in Condition 7, which arranged green flashes and only 27:1 or 1:27 components. Landon and Davison (2001) obtained a similar result and argued that this could be because a location where a reinforcer had occurred is more predictive of the arranged reinforcer ratio in conditions arranging only 27:1 or 1:27 components than in those that arrange a range of different reinforcer ratios. Indeed, sensitivities to reinforcement following the first reinforcer increased considerably more in Condition 7 than in Condition 11, in which the range of component reinforcer ratios was presented with nondifferential stimuli.

The findings that signaling components did not affect the emergence of preference pulses does not challenge the accumulator model proposed by Davison and Baum (2000) because it shows that the absence of differential stimuli for components in their experiment was not responsible for the reduction of preference over time that they reported. This finding is also consistent with the results from Davison and Baum (2002) who reported that preference during blackout periods and unsignaled extinction similarly moved towards indifference.

Effects of Presence Versus Absence of a COD

In Conditions 7 to 11, where a COD was used, log response ratios reached more extreme levels than in the corresponding conditions without a COD (Figures 4 & 5), confirming the findings of Davison and Baum (2002). When a COD was in effect, log response ratios in components were more separated, indicating that behavior was more strongly controlled by component reinforcer ratios. Consequently, sensitivity to reinforcement in COD conditions was higher than in corresponding no-COD conditions (Figure 8). These results are consistent with findings in standard steady-state research. Both Herrnstein (1961) and Shull and Pliskoff (1967) reported that a minimum COD was necessary to produce matching and that CODs below this minimum resulted in considerable undermatching to obtained reinforcer ratios.

In addition, discontinuation shifted preference much more towards indifference when a COD was used than when no COD was used. This difference is consistent with the finding that log response ratios in conditions without a COD were generally less extreme than in those that used a COD.

The effect of the COD could be observed by analyzing the changes in log response ratios with increasing time since reinforcement. Virtually no preference pulses were present before a COD was arranged (Figure 10). Preference was biased to the response that had been reinforced most recently, and remained at the same level with increasing time since reinforcement. By contrast, pronounced preference pulses were obtained when a COD was implemented (Figures 10 & 11). As Davison and Baum (2002) reported, preference immediately following reinforcement was strongly towards the just-reinforced alternative, and gradually moved towards indifference after about 25 s.

How can these effects of arranging CODs be explained? Silberberg and Fantino (1970) reported high response rates during CODs for both leaner and richer alternative on concurrent VI schedules. These response bursts were not limited to the COD and continued after the COD had terminated. This resulted in a brief period of overmatching to the alternative to which the subjects had just changed. In their Experiment 3, Silberberg and Fantino arranged blackouts during the COD that drastically reduced responding during that period and more undermatching was obtained. Given that reinforcement often follows changeovers (Dreyfus, Dorman, Fetterman, & Stubbs, 1982), the preference pulse seen here in COD conditions might result from the reinforcement of response runs on single alternatives rather than, in no-COD conditions, of runs of responses comprising both alternatives. However, some evidence against the view that pulses are a result of the reinforcement of response runs comes from Landon, Davison, and Elliffe (2002). In a steady-state concurrent-schedule procedure, post-reinforcer response rates reached their highest levels at around 5 s to 10 s after reinforcement, not immediately after the access to the reinforcer terminated.

Further evidence against this notion comes from the different sizes of preference pulses after reinforcers found here. Reinforcement of response runs would predict that post-reinforcer preference pulses would be greater on the leaner than on the richer alternative. Because of the higher probability of reinforcement following changeovers to leaner alternatives (Dreyfus et al., 1982), post-reinforcer pulses on the higher reinforcer-rate alternative would have contained a lower proportion of reinforcers immediately following a COD. We found, however, larger preference pulses on the higher reinforcer-rate alternative (Figure 13). This is further evidence against the hypothesis of reinforcement of response runs accounting for the COD effect.

Effects of Prior Exposure to COD

Effects of previous exposure to CODs can be explored by comparing performance in replications of previous conditions following exposure to CODs within the current data set. Condition 12 was a repetition of Condition 1 (no COD, differential stimuli), and Condition 13 a repetition of Conditions 2, 3, and 4 (no COD, nondifferential stimuli). Log response ratios in the post-COD replications generally reached more extreme values than in the initial conditions (Figures 4 & 5). Sensitivities to reinforcement were also significantly higher in Condition 12 versus Condition 1 and Condition 13 versus Condition 4 (Figure 8; randomization test, two-tailed, $p < .05$).

Landon and Davison (2001) reported that sensitivity values were higher in replications of previous conditions. The increases in sensitivity found here, however, cannot be completely accounted for by continued exposure to the experimental conditions. Although sensitivities in the present experiment increased with continued exposure to the same experimental conditions (Conditions 2 to 4; Conditions 9 & 10), this increase was in both cases significant for only 4 of the 6 subjects.

In addition, sensitivity values increased considerably in Condition 7 as compared to Condition 6, after a COD had been introduced (Figure 8).

An effect of prior exposure to COD was shown in preference pulses. Whereas virtually no pulses were present in Conditions 1 and 2 to 4, preference pulses can be seen in replications of these conditions after exposure to a COD (Conditions 12 & 13, respectively). The intervening series of conditions with COD had an irreversible effect, although the preference pulses were smaller in post-COD conditions than in COD conditions.

Shull and Pliskoff (1967) reported a similar irreversible effect of exposure to COD when CODs were introduced in an ascending order and gradually removed in a descending order (see the reanalysis in Figure 7.1 of Davison & McCarthy, 1988). Preference in a concurrent VI 60-s VI 180-s schedule was initially indifferent with no COD and developed overmatching when CODs were increased to 20 s. When the COD was decreased again, preference became more indifferent, but remained strongly towards the richer alternative even when the COD was reduced to 0 s.

Implications for Steady-State Concurrent Schedules

Because levels of preference immediately following reinforcers were different from levels later in interreinforcer intervals, overall measures of sensitivity to reinforcement would be expected to be differentially affected by responding at different times after reinforcers. The present experiment arranged an overall probability of reinforcement of .037 per second. Because the probability that a reinforcer would occur within the first 25 s (the approximate time at which preference pulses ended after reinforcers) was .67, overall response-rate measures comprised a considerable amount of data from within preference pulses. Sensitivities to reinforcement were calculated separately for the times within and following the preference pulse. As Figure 14 shows, for all conditions, sensitivity measures in Time Bins 0 to 4 were higher than those for Bins 5 to 11. Thus, any overall sessional performance measure convolves these differing aspects of performance, and whole-session measures of sensitivity provide an incomplete picture of the results of the

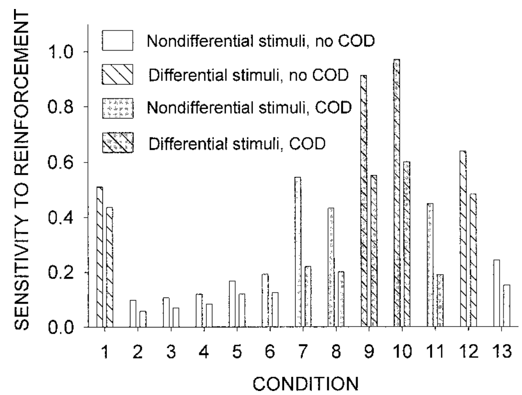

Fig. 14. Current-component sensitivity to reinforcement for Time Bins 1 to 4 (left bar of each pair) and for Time Bins 5 to 11 (right bar of each pair) for each condition.

present experiment. An example of the latter is when performance is compared under COD and no-COD conditions.

While sensitivities to reinforcement in COD conditions were larger than in no-COD conditions, these differences cannot be entirely accounted for by the presence or absence of preference pulses. Although the pulses were both more frequent and larger on the richer alternative (Figure 13), resulting in more extreme between-component performance differentials, sensitivity values in Time Bins 5 to 11 were also higher when a COD was arranged than when it was not. Thus, both local short-term, and more long-term, control of preference was affected by the presence or absence of a COD, as well as by prior exposure to a COD. Thus, the effect of overall reinforcer rate on sensitivity to reinforcement reported by Alsop and Elliffe (1988) could arise largely from postreinforcer pulses taking up proportionally more of sessions at higher reinforcer rates, but also, probably to a lesser extent, from differences in preference that remain in the longer term.

In related research using a steady-state procedure, Baum, Schwendiman, and Bell (1999) reported that animals stayed only briefly at the nonpreferred alternative when no COD and unequal reinforcer ratios were arranged. It is possible, then, that the preference pulses on the leaner alternative were smaller and shorter because the subjects were more likely to change over after reinforcement on the lean, rather than the richer alternative.

Davison and Baum (2002) demonstrated that the control of preference pulses was not entirely due to the just-received reinforcer. Sequences of two reinforcers on the same alternative resulted in stronger preference compared with preference following an alternation of reinforcers. To account for such effects, Davison and Baum suggested an additional longer-term, more slowly changing, accumulator. The present data suggest that stimulus control over component performances may be more related to the longer-term accumulator than to the shorter-term accumulator. Choice at the start of a signaled component remained under stimulus control for 23 hr after the subject last saw that stimulus and experienced the associated reinforcer ratio. In other words, stimulus control may relate to stimuli signaling molar reinforcer-ratio conditions.

In steady-state concurrent VI VI experiments, different reinforcer ratios (that is, different conditions) are not normally differentially signaled (but see Hanna et al., 1992). Should steady-state performance, therefore, be expected to be similar to the nondifferentially signaled performances here? Probably not. With extended exposures to constant reinforcer ratios, stimulus control by environmental stimuli will surely develop. But this may highlight an important difference between steady-state procedures and the procedures used here. In the steady state, when reinforcer conditions change, subjects' choice adapts not only to the new reinforcer ratio, but also to the altered relation between environmental stimuli and the reinforcer ratio—they need to relearn stimulus control. Thus, an alternative view of research using the Belke and Heyman (1994) procedure is that rather than learning being faster when environmental conditions change faster, learning speed may actually be attenuated in steady-state procedures because stimulus control as well as reinforcer control is relearned when conditions are changed. Further, because similar reinforcer conditions are in effect for a longer period of time in the steady state, the stimulus control would be expected to be stronger and hence to take longer to relearn than when the reinforcer ratios change frequently.

The present experiment demonstrated the limitation of overall measures of sensitivity to reinforcement because different behavioral processes contribute differentially to the overall measure of sensitivity within a single component. The effects of preference pulses revealed that a full understanding of preference requires analyzing data at different levels simultaneously.

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